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SINGLE MODE OPTICAL WAVEGUIDE DESIGN INVESTIGATION.(U)
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Single Mode Optical Waveguide
Design Investigation

Progress Report 3

Submitted to Dr. W. K. Burns

Contract N00173-80-C-0563

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Single Mode Optical Waveguide Design Investigation

Progress Report 3

1. Summary

1.1 A total of six fibers have been fabricated with parameters fitting the design matrix.

1.2 Microbend sensitivity measurements have been made on five of the fibers.

1.3 The data collection procedure for the angular offset sensitivity measurements has been modified and automated in order to improve measurement reliability.

1.4 Lateral offset measurements have been made on two fibers as a function of V-value and the data fitted to the equation given in Progress Report 2, (paragraph 2.1.3).

2. Fabrication

Four additional fibers were chosen this period, the parameters of which, fit the design matrix. Two of the remaining five fibers will now have a different refractive index profile design as agreed upon with the sponsor. The depressed cladding design is shown in Figure 1. The matrix points for the design are (a) $\Delta = 0.005$, $2a = 6\,\mu m$ and (b) $\Delta = 0.007$, $2\Delta = 5.2\,\mu m$.

The parameters of the six fibers chosen to date are reviewed in Table 1.

Table 1

Fiber #	λ_c(transmission)	λ_c(RNF)	Core-Diameter
502905	1060 nm	1140	6.4 µm
503403	1130	1360	6.5
506803	1183	1236	5.2
507205	950	1056	7.0
508305	1231	-	5.2
506902	760	863	5.1

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3. Measurements and Analysis

3.1 Microbend Sensitivity Measurements

3.1.1 Propagation Curve

The microbend sensitivity test has been performed on 5 fibers that fit the NRL design matrix. This test involves "weaving" the test fiber through pin arrays of different pin spacings (see Progress Report #1). The measurements are conducted for four different pin array spacings. The nominal pin array spacings are 8 mm, 5 mm, 4 mm and 3 mm, respectively. The perturbation spectrum applied by the pin arrays depends on the nominal pin array spacing and the pin diameter. The highest frequency perturbation and also the most severe microbend is expected to be applied by the pin array with 3 mm spacing, with correspondingly lower perturbations with larger pin array spacings. To obtain the highest frequency applied by each of the pin arrays, a calibration has to be performed. The results indicate that the pin arrays apply discrete, narrow bands of perturbations. The results of the calibration on the perturbation band with lowest wavelength (i.e. highest frequency) are listed in Table 2. In this calibration, a fiber with known parameters is used.

Table 2

CALIBRATION OF PIN-ARRAY

Estimates of Λ_i

d_p (mm)	L_i (mm)	Λ_i (mm) from LP_{01}	Λ_i (mm) from LP_{11}
	8	0.62	0.72
0.4	5	0.39	0.48
	3	0.26	0.29

(Calibration fiber parameters: $\Delta = 0.0054$, $\lambda_c = 1140$ nm)

In microbend sensitivity measurements, the threshold value of the wavelength and the corresponding V-value for the microbend loss is obtained for each of the pin arrays. An example of the measurement is shown in Figure 2. In this figure, for software reasons, the zero excess loss level is represented by the 3 dB value. From a knowledge of the V-values obtained from threshold wavelengths λ_1^{01} etc., and the corresponding perturbation

band with the lowest wavelength, the propagation curve can be obtained. The propagation curve obtained by this procedure is shown in Figure 3 and is derived from the microbend data shown in Figure 2.

The results indicate the feasibility of the new technique to obtain the propagation curve for a single-mode waveguide. This procedure can also be used to obtain the equivalent step index difference Δ_{EQ}^{ST} of any fiber with arbitrary profile. The equivalent step fiber derived using this procedure will have the same propagation constant β as the test fiber.

3.1.2 Relative Microbending Sensitivity

In addition, the fibers measured so far have been compared for their relative microbend sensitivity. For this purpose, fibers 502905, 503103, 503403, and 507205 have been considered in one group having a core diameter of 6.7 μm. The second group consists of fibers 506803 and 506902 with a core diameter of 5.2 μm. The microbend sensitivity of these two groups of fibers is shown in Figures 4 and 5, respectively. In these figures, $V_{\mu B}$, defined previously, is plotted as a function of perturbation severity given by the pin array spacing. Results indicate that as the relative index increases for a given core diameter, the microbending sensitivity decreases. The microbend sensitivity for the two groups follows qualitatively the theoretical expectations. The results also confirm the theoretical expectations that microbend sensitivity depends on core diameter, with the smaller core diameter fibers exhibiting lesser sensitivity. For example, fiber 506902 has a similar microbend sensitivity as fibers 502905 etc. even though it has a smaller Δ because of its smaller core diameter.

It is important to note that the operating wavelength range for any perturbation value can be determined from the microbending results as displayed in Figures 4 and 5. For example, if fiber # 503103 is subjected to microbend conditions equivalent to those applied by 5 mm pin-array, the fiber system cannot operate at wavelengths with V-values below 2.0. With fiber # 507205 ($\Delta \sim 0.31$), even under the least severe microbend conditions considered in this study (i.e. 8 mm perturber), the fiber system cannot operate for $V < 2.1$. For this fiber system, the operating range is quite restricted with $2.4 > V_{op} > 2.1$ even under "quite moderate" microbend perturbations.

3.2 Lateral Offset Sensitivity Measurement

3.2.1 Results

As indicated in Progress Report #2, the equipment has been tested for reproducibility and preliminary results were

obtained on a test fiber. An expression that fits the experimental results was derived.

During this period, measurements have been made on fibers 502905 and 503103 which fit the design matrix. The cutoff wavelengths and the experimental results at various wavelengths are listed in Table 3.

Table 3

OFFSET SENSITIVITY MEASUREMENT DATA

Fiber #	λ_c^{RNF} (nm)	λ (nm)	V	δ_{1dB} (μm) Fiber = 1m	1.1 km
		1100	2.50	1.8	
		1300	2.11	2.1	
	1140	1390	1.97	2.2	
502905		1500	1.83	2.55	
		1650	1.66	2.90	
		1100	2.78	2.0	1.8
		1200	2.55	1.9	2.0
503103	1274	1240	2.47	1.9	1.8
		1300	2.35	2.1	2.1
		1360	2.25	2.3	1.9
		1410	2.17	2.3	2.0
		1500	2.04	2.4	2.2
		1650	1.86	2.7	-

The results δ_{1dB}, the lateral offset in microns for 1 dB excess loss, are plotted in Figure 6, as a function of normalized frequency V, for fiber #503103. In this calculation, the cutoff wavelength from the refracted near field technique is used. This value of the cutoff wavelength is expected to represent the intrinsic guide value. Using this value the region of double-mode propagation is shown in the figure. In this figure, curve A represents the results obtained for a test fiber length of ~1.0 m, and curve B, is for a test fiber length of 1.1 km.

3.2.2 Discussion

The data shown in Figure 6 for fiber # 503103 show that δ_{1dB} values drop off gradually as V-value is increased from 1.7 to 2.5. At this point δ_{1dB} starts to increase. This increase can be attributed to the propagation of (second) higher order mode. Some of the anomaly noticed in the results near the V-value of 2.2 may be due to (OH) absorption band at 1390 nm. The V-value range covered by this absorption band is indicated in the figure.

Also shown in Figure 6 (curve B) are the lateral offset sensitivity results for a 1.1 km test fiber length. These results indicate that in the single-mode region (i.e. $V < 2.41$) δ_{1dB} values are lower for the larger length case. This difference may be due to variations in fiber parameters with length or due to absorption gradients in the radial direction both of which can have effect on the spot size and hence the offset sensitivity. The length dependent variation observed in the results, indicate that proper selection of the test fiber length is essential.

Even after taking these anomalies into account, the data indicates that δ_{dB} values vary by a large amount (~60%) as the V-value changes from 1.66 to 2.5. Under these conditions, (δ_{dB}/a) cannot be assumed constant for this range of V-values. As indicated in Progress Report #2, the parameter $(\delta_{dB}/w_o/a)$ where w_o is the spot size, is better suited. This parameter has been evaluated at various wavelengths for fibers # 502905 and 503103 and has been found to have average values of 1.7 μm and 1.82 μm, respectively. The parameter $(\delta_{dB}/w_o/a)$ varies less than 5% in the V-value range from 1.66 to 2.5. From the known values of a and Δ, the values of the constant C_o in the expression:

$$\gamma_{dB} = C_o a^2 \Delta \left(\frac{\delta}{w_o}\right)^2$$

are given by 41.8 and 30.6 for fibers # 502905 and 503103 respectively. The core radius a, spot size w_o and lateral misalignment δ are all in microns. The results on the lateral offset sensitivity are summarized in Table 4.

Table 4

SUMMARY: OFFSET SENSITIVITY MEASUREMENT

Fiber #	$\left(\frac{\delta_o}{w_o/a}\right)$	2a (μm)	Δ	C_o
502905	1.7	6.4	0.441	41.8
503103	1.82	6.3	0.571	30.6

3.3 Angular Offset Sensitivity

To improve the reproducibility of this measurements, the data collection procedure has been improved and automated. As indicated in Progress Report #2, the procedure planned originally involved the manual adjustment of angular positions. To improve the reproducibility, the angular motion as well as the lateral movement is computer controlled using stepping motors. Also, to minimize the lateral offset effects, the fiber ends are laterally adjusted for peak power after each increment in angular misalignment.

Preliminary results on fiber 502905 ($\Delta \sim 0.5\%$) indicate that a 3 dB excess loss level is reached at an angular misalignment level of approximately 4°.

4. Program

1. Fabricate and select the remaining fibers within the design matrix.

2. Complete the microbend, lateral and angular offset measurements.

3. Final analysis and report of the single mode design study.

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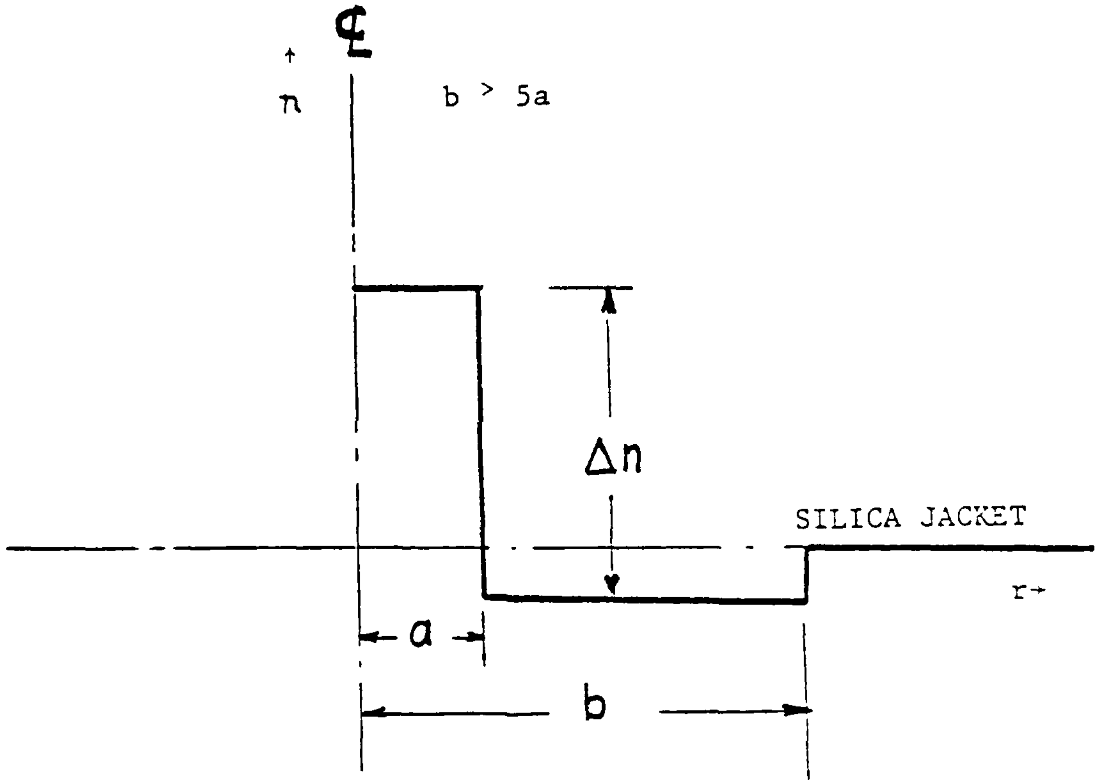


Figure 1

Refractive Index Profile Depressed Cladding Design

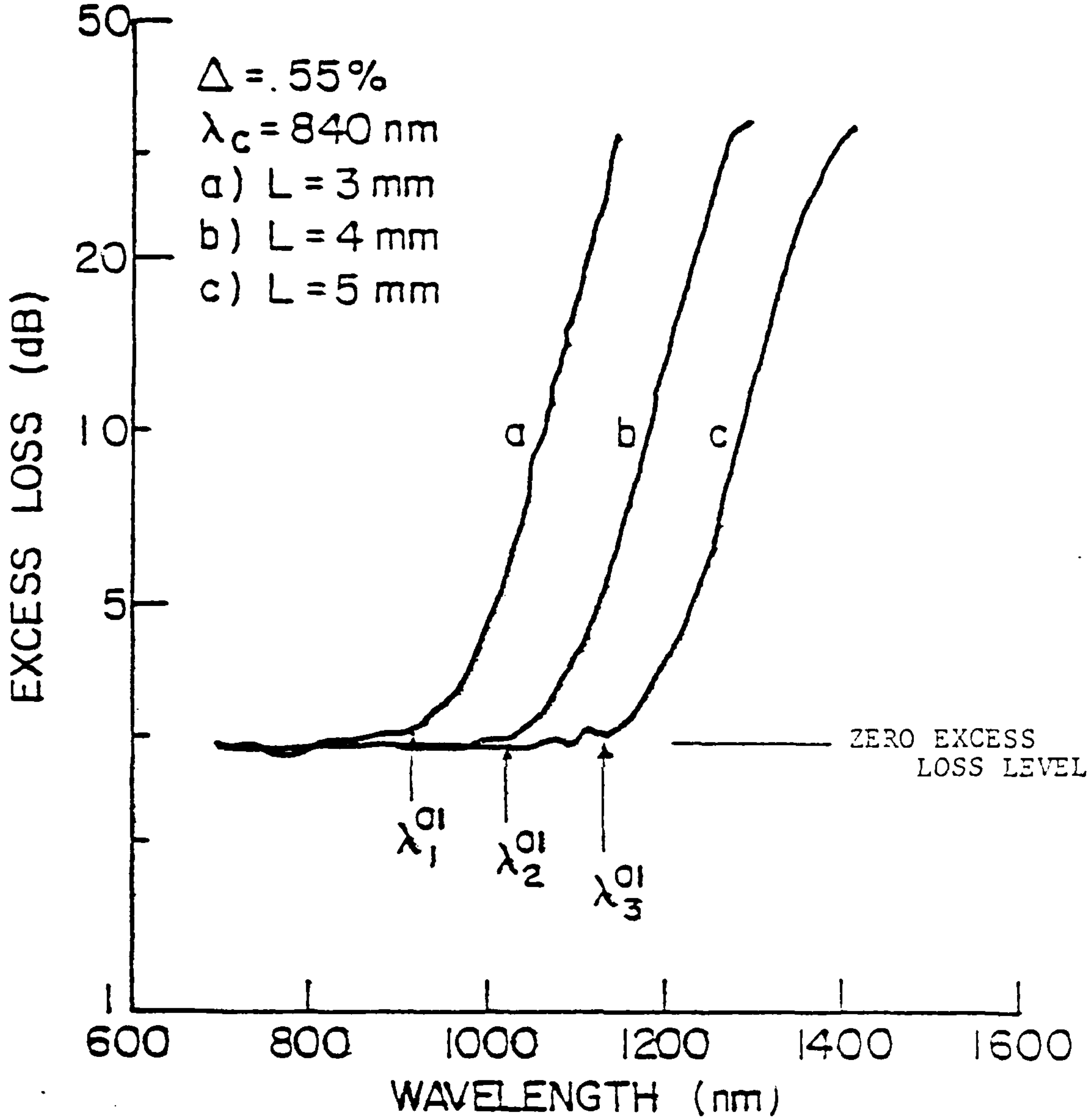


Figure 2

Microbend Sensitivity Measurements

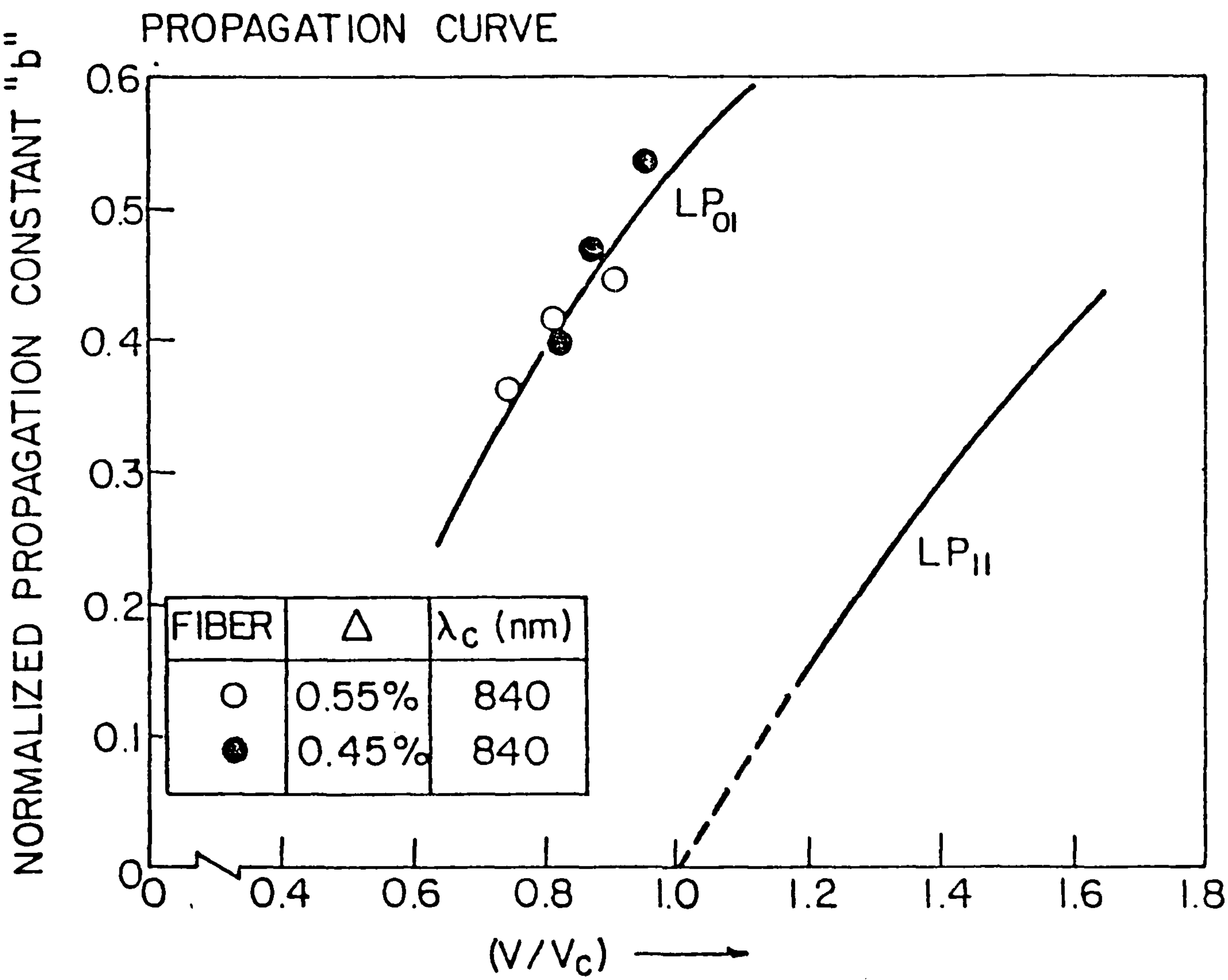
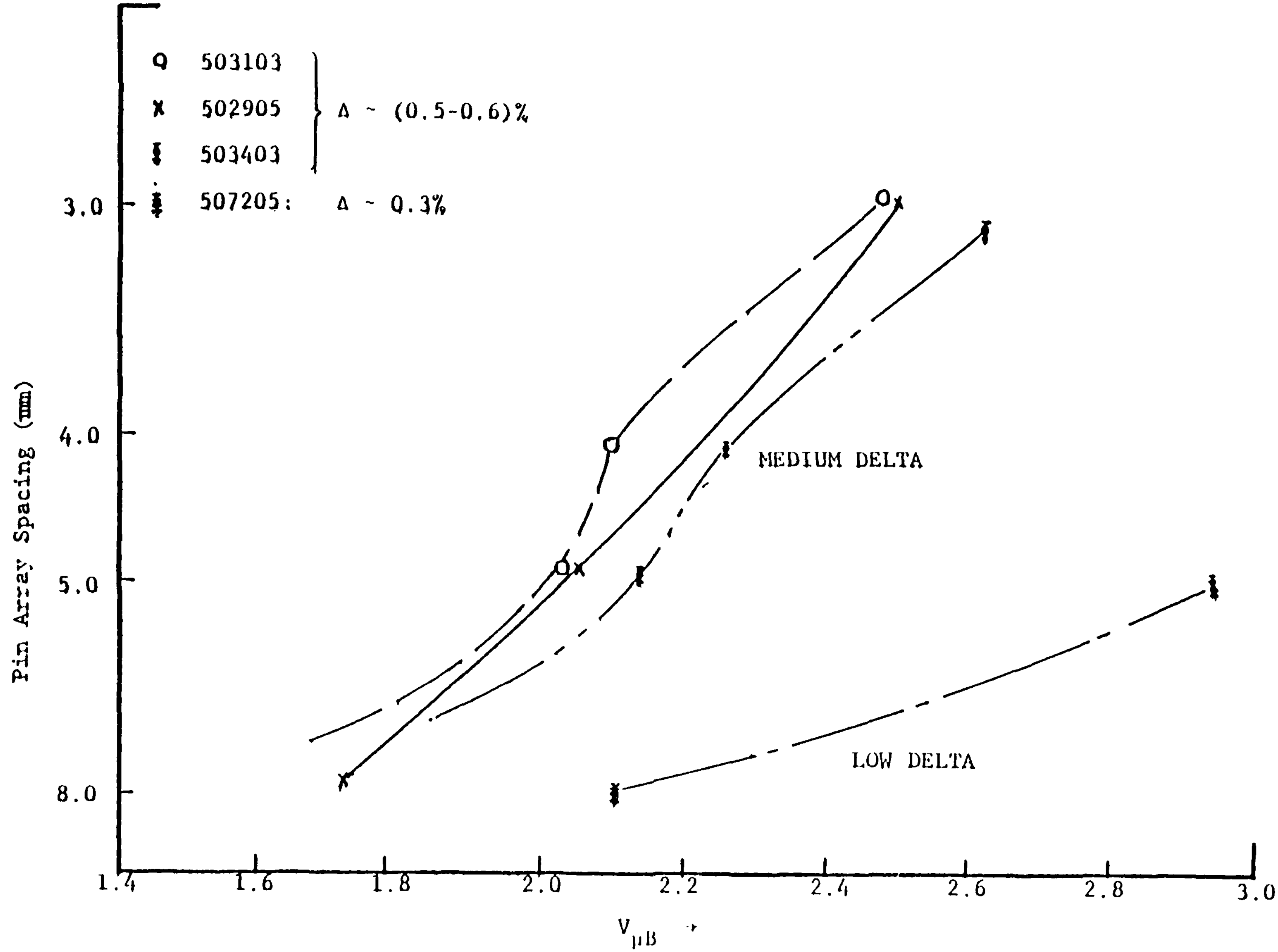


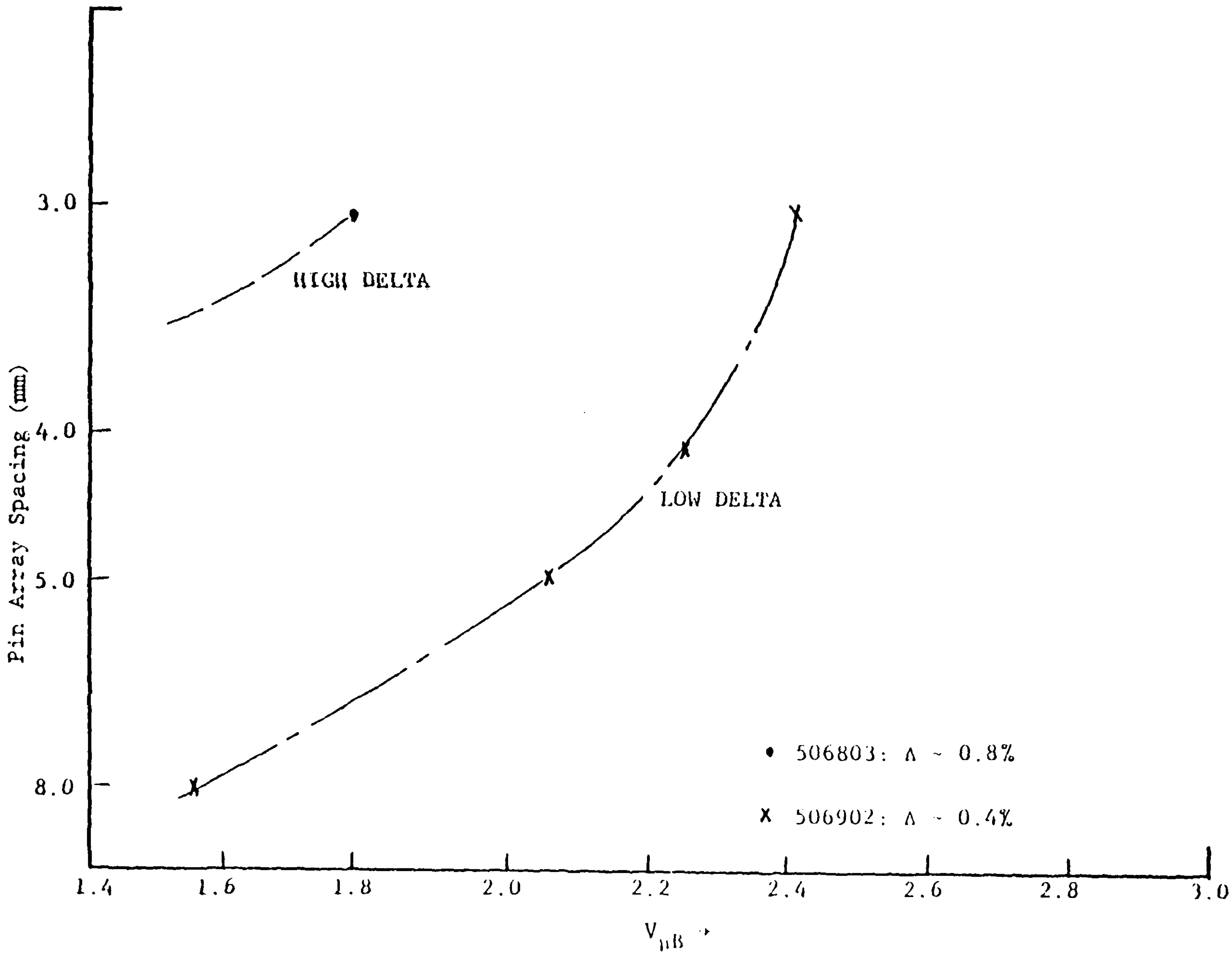
Figure 3

Propagation Curve Derived from Linear Pin Array Microbend Sensitivity Measurements



Comparative Study of Microbend Sensitivity: Effect of Δ
FIBER DIAMETER 2a ≈ 6.7 μm

Figure 4



Comparative Study of Microbend Sensitivity: Effect of Λ

FIBER DIAMETER 2a - 5.2 μm

Figure

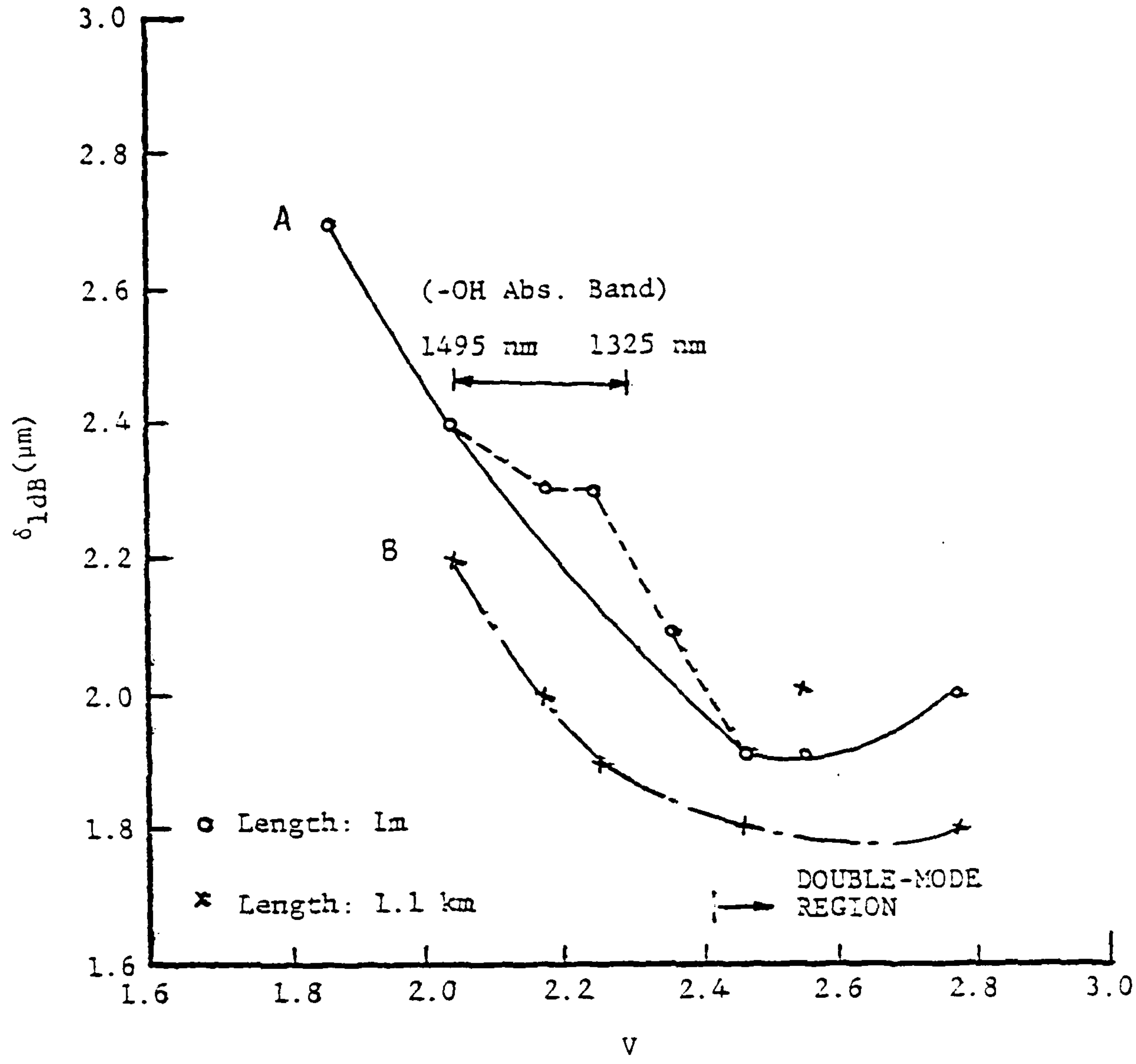


Figure 6

Lateral Offset Sensivitity Measurements
Fiber # 503103
Curve A: Fiber Length 1 meter
Curve B: Fiber Length 1.1 kilometer